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A proposal of criteria for the evaluation of  
industrial physical-plant utilization.

Gantz, Saxe Perry

Purdue University

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A PROPOSAL OF CRITERIA FOR THE EVALUATION OF INDUSTRIAL  
PHYSICAL-PLANT UTILIZATION

A Thesis

Submitted to the Faculty

of

Purdue University

by

Saxe Perry Gantz

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in Industrial Engineering

June, 1950

Theses  
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A THESIS SUBMITTED TO THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES

IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

JOHN H. HARRIS

OF

THE UNIVERSITY OF CALIFORNIA

AT

SAN DIEGO

IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE

OF

DOCTOR OF PHILOSOPHY IN PHYSICS

June, 1950



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## ABSTRACT

An extensive survey of the literature on plant layout was made. No quantitative measures of evaluating plant layouts were encountered. From the considerations of good plant layout practice as found in the literature eleven measurable indices were developed and proposed as criteria of effective physical-plant utilization.

The criteria were applied to a small, newly formed plant in Indiana before and after a change in layout which was made to adopt methods and layout improvements. This demonstrated the applicability of the several indices to the plant in question, and demonstrated their use.

A critique of the eleven indices was made in which their applicability to continuous, intermittent, and jobbing layouts were discussed.

## CONCLUSIONS AND RECOMMENDATIONS

Eleven indices of effective physical plant utilization have been proposed. One has been set aside as being of doubtful value. Of the remaining ten, all seem suitable and are recommended for evaluation of a continuous manufacturing layout with one considered to be of secondary importance. Three indices appear suitable and are recommended for evaluation of jobbing layouts. The intermittent plant may be evaluated by either three or ten indices depending upon whether it tools for continuous manufacture on some products. The employment of the indices as criteria of layout is recommended for:

### Continuous Manufacture

1. Index of Indirect Materials Handling
2. Index of Direct Materials Handling
3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading

An extensive survey of the literature in Japan has been made. In particular, a number of existing physical factors have been examined. The comparative analysis of good and bad physical factors as found in the literature shows that the factors were developed and proposed in terms of the factors of physical fitness.

The physical factors applied in a study, namely, physical fitness in Japan, have been applied in a study in Japan which was made for other nations and Japan. This demonstrated the applicability of the physical factors in the study in Japan, and demonstrated their use. A review of the physical factors was made in terms of their applicability to various nations, including Japan, and Japan's physical fitness was discussed.

## CONCLUSIONS AND RECOMMENDATIONS

Physical fitness of effective physical fitness utilization have been proposed. One has been not only as being of physical fitness, but also as being of physical fitness and as recommended for evaluation of a physical fitness utilization. Japan with one considered as an of secondary importance. Three physical fitness factors and are recommended for evaluation of physical fitness. The physical fitness factors are recommended by either three or four factors depending upon whether it is for continuous maintenance or new products. The physical fitness factors as criteria of Japan is recommended for:

### Continuous Maintenance

1. Index of Physical Fitness
2. Index of Physical Fitness
3. Index of Physical Fitness
4. Index of Physical Fitness



5. Secondary Index of Automatic Machinery Loading
6. Index of Flexibility
7. Index of Floor Area Loading Density
8. Index of Aisle Wastage
9. Time Index
11. Inventory Index

#### Jobbing

3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading
7. Index of Floor Area Loading Density

The indices, although presently usable, are significant only in comparing one layout of a plant with another of the same plant. There are no developed standards against which numerical values of the separate indices may be compared. Neither is there established any relative importance of the indices. It would seem, therefore, that a wide field of further study exists, namely - that of relative order of importance of the indices, and that of the importance of specific index values. Also, since improvements in industry must pay for themselves in dollars and cents, an appropriate area of investigation would be the correlation of the criteria indices against costs.





A PROPOSAL OF CRITERIA FOR THE EVALUATION OF INDUSTRIAL  
PHYSICAL-PLANT UTILIZATION

THE PROBLEM

It is a recognized fact that plant layout is an extremely important function of planners in modern day industry. Our problem here is: how do planners in all industries effect physical-plant utilization, and how can the effectiveness of their layouts be measured, rather than the consideration of any specific industry with its specific planners. We define plant layout as the physical arrangement of the productive facilities of a manufacturing enterprise. The arrangement of building interiors, machines, services and associated equipment are thus included.

It is a recognized fact that Japan is an extremely important  
source of raw materials for industry. Our position here is; how  
do we plan to get the maximum effect of Japan's resources, and  
how can the development of their Japan be improved, which has the  
consequence of any specific industry with the specific industry. We  
define first Japan as the physical arrangement of the productive  
resources of a manufacturing enterprise. The arrangement of building  
interior, machines, factories and associated equipment are the physical

## GENERAL PROCEDURE

Much has been written on the subject of physical-plant utilization, or plant layout; but, so far as is known, there have been developed no measurable indices of the effectiveness of any plant layout. Accordingly, it is proposed herein to review what has been written on the subject in broad, general terms, briefly setting forth principles, ideas and helpful hints for informational purposes. We shall then undertake the development of measurable criteria for evaluating the effectiveness of any plant layout. It is then proposed to apply the criteria to an existing plant as an example of their application. Following will be a criticism of the criteria and a recommendation relative to those that presently seem useful and those that appear to require further study.

There has been written in the subject of present-day education, on page 10, that, as far as is known, there have been developed no systematic studies of the effectiveness of any kind of physical education. It is proposed herein to review what has been written on the subject in books, journal articles, and other sources, and to make a critical study of the information presented. The purpose of this study is to determine the effectiveness of physical education in the development of character and to suggest ways of improving the effectiveness of any kind of physical education. It is also proposed to apply the results to all existing forms of physical education. Following will be a synthesis of the information and a recommendation as to what that presently exists and what should be done to improve further study.



## REVIEW OF LITERATURE

The following review of what has been written on plant layout is presented in sections by subject. This author makes no claim of complete coverage of everything ever written on plant layout but does attest to an intensive survey of the literature. For further information on each subject, the reader is referred to the bibliography by footnotes at the close of each section.

### The Process Chart

Quoting Dr. Marvin E. Mundel, "Process Charts - Product Analysis are a graphic means of portraying the separable steps of the procedure involved in performing the necessary work required to modify a product from one stage of completion to another."

Use of the Process Chart - Product Analysis can be helpful and should be made as a preliminary in rearranging an existing plant, in laying out a new department in an existing plant, and in designing the layout of a new plant.

(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22)

### Scale Layouts

A scale layout is a small model layout of a plant or of a portion thereof performed in two or three dimensions from which the layout

The following review of what has been written on plant layout is presented to students of subjects. This review serves as a basis of analysis and comparison of existing work and to plant layout and how related to an industrial survey of the literature. For further information on each subject, the reader is referred to the bibliography by location in the list of references.

### The Process Chart

According to Dr. J. B. Smith, "Process Chart - A record analysis and a graphic means of portraying the sequence of the procedure involved in performing the necessary work required to actually produce from raw stage of production to market."

Use of the Process Chart - Process analysis can be defined and should be made as a preliminary to reorganizing an existing plant, in laying out a new department in an existing plant, and in designing the layout of a new plant.

- (1) 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19.
20. 21. 22.

### Scale Layouts

A scale layout is a small model layout of a plant or of a portion thereof performed in two or three dimensions from which the layout

engineer visualizes and studies the arrangement of the plant. Scales commonly used are  $\frac{1}{4}" = 1 \text{ ft.}$ ;  $\frac{3}{8}" = 1 \text{ ft.}$ ; and  $\frac{1}{2}" = 1 \text{ ft.}$  The model layout is invariably executed as exactly to scale as possible.

The design of a plant layout is generally undertaken by means of a scale method. It is believed that some scale method must be used.

Templates. Templates are two dimensional models of machinery and service equipment cut exactly to scale portraying machinery and service equipment profiles as viewed from above.

The use of templates cut to scale for all machinery and then fitted onto a board representing the plant floor area is probably the most widely used method of arriving at a final layout design. The templates are fitted, juggled, and refitted until a layout that appears optimum to the layout engineer results.

(2, 3, 4, 7, 8, 10, 12, 13, 15, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39)

Scale Models. Scale models are small, three-dimensional replicas of machinery and service equipment made exactly to scale portraying machinery and service equipment realistically as viewed from any direction.

More and more industrial concerns are discarding the template method in favor of the use of true scale models. This allows a true three-dimensional model setup and is particularly useful in planning a layout where the building is more than one story high. Requirements are that the models must be durable, exactly scaled, recognizable, inexpensive, and light in color.

(2, 9, 10, 12, 19, 20, 22, 23, 24, 25, 26, 29, 32, 36, 40, 41, 42, 43, 44, 45, 46)

Use of Color. Where one machine is used in the manufacture of more than one part, it sometimes is helpful to use different colors on the same



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template or model to represent the production time spent on each part. That is to say, a template 30% blue, 50% white, and 20% yellow could indicate those percentages of production time spent on three different parts.

(9, 47)

Photographs. It is considered good practice to photograph one scale layout before it is torn down and another one made. The photographs allow a comparison of two or more layouts and also can serve as a guide in arranging the actual machinery on the plant floor. If colors are used in the scale layouts, they should be light.

(25, 40)

### Materials Handling

Materials handling is here defined as the handling incident to the movement of production materials from raw stores to the first operation station, from there to the next, and so on through the entire production process to finished stores. The handling ordinarily is performed by special non-production personnel and/or sometimes by special equipment.

Much has been written on the subject of materials handling. Suffice it to say that any materials handling cost is a loss since materials handling is a non-productive function. There are, however, ways of keeping this necessary evil at a minimum.

Machinery Arrangement. By arranging machines in order of operation sequence, a part in manufacture can be passed from tote box to adjacent tote box by machine operators, thus eliminating materials handling as such. To accomplish this, the old practice of grouping similar-type machines into departments or divisions must be done away with, although this also has other advantageous features.





Conveyors and Chutes. Mechanical conveyors and chutes for transporting materials from operation to operation are becoming more and more widely used. Layout engineers are availing themselves of the increased diversity of types offered for sale in present day markets. It is safe to say that a mechanical conveyor can be found to suit any materials handling problem. Many concerns have reported great savings with the installation of conveyor systems, several companies' savings being large enough to pay for the installations in the first year. The usual types now in use are electrical, hydraulic, and gravity-operated conveyors. For the several-story plant, a gravity feed from the top floor down is an opportunity for savings in materials handling costs of which more concerns could well afford to take advantage. Mechanical conveyors are a necessity in true mass production. (3, 5, 7, 8, 9, 10, 11, 15, 17, 18, 19, 20, 21, 22, 23, 27, 28, 32, 33, 34, 35, 36, 37, 38, 39, 42, 44, 48, 49, 51, 52, 53, 54, 55, 56, 57, 58, 59)

#### Normal Flow

By definition, normal flow means flow in accordance with the natural sequence of operations as determined by the nature of the production materials.

Quoting Allan H. Mogensen: "It is evident, of course, that the process itself will have a great deal to do with the design and layout of the plant, inasmuch as the raw materials pass in at one end of the plant, flow through a number of given processes, and emerge at the other end as finished products and by-products."

The DuPont nylon plants are excellent examples of industrial establishments where the process determines the design of the plant. The raw material

The first of these is the fact that the hydraulic  
 system is a closed system. This means that the  
 fluid is contained within a fixed volume and  
 cannot escape. This is in contrast to a  
 pneumatic system, where the fluid is air and  
 can escape through leaks. The second point  
 is that hydraulic systems are capable of  
 transmitting power over long distances. This  
 is because the fluid is incompressible and  
 can therefore transmit the force applied to it  
 without loss. The third point is that  
 hydraulic systems are capable of operating at  
 high pressures. This is because the fluid is  
 incompressible and can therefore withstand  
 high pressures without being compressed. The  
 fourth point is that hydraulic systems are  
 capable of operating at low speeds. This is  
 because the fluid is incompressible and can  
 therefore move slowly without being compressed.

The fifth point is that hydraulic systems  
 are capable of operating at high speeds. This  
 is because the fluid is incompressible and  
 can therefore move quickly without being  
 compressed. The sixth point is that  
 hydraulic systems are capable of operating  
 at low pressures. This is because the fluid  
 is incompressible and can therefore withstand  
 low pressures without being compressed. The  
 seventh point is that hydraulic systems are  
 capable of operating at high temperatures. This  
 is because the fluid is incompressible and  
 can therefore withstand high temperatures  
 without being compressed. The eighth point  
 is that hydraulic systems are capable of  
 operating at low temperatures. This is  
 because the fluid is incompressible and can  
 therefore withstand low temperatures without  
 being compressed.

in liquid solution is pumped up to the fifth story at one end of the plant. From there the production material flows downward and forward to emerge at the other end of the plant as finished spools of nylon thread.

(2, 7, 19, 20, 22, 33, 35, 37, 38, 55)

### Number of Machines

The machines spoken of here are defined as production machinery and equipment.

An important economic consideration in any layout is that of using multiple tooling wherever feasible in order to hold the number of machines to a minimum. In this way, machinery depreciation, a very important cost item in low volume production, can be held down.

(2, 22, 60)

### Multi-Machine Operation

We define multi-machine operation as the case where one person operates two or more production machines alternately, unloading and loading one while the other or others are operating.

Where machine time represents the greater part of a work cycle, savings can be realized by grouping two or more machines together for the use of one operator. A Man and Multi-Machine Time Chart should be made and used as a guide in this undertaking. This chart is a graphic means of portraying the work an operator performs when working with machines where the work of the machines is a controlling factor.

(1, 2, 7, 11, 22, 28, 54, 61)



to limit exhaust is passed up to the fifth story at the end of the plant,  
 from there the exhausted material flows down to and returns to storage  
 at the other end of the plant as finished goods or other uses.

### Process of Production

The machine system of work is divided as follows: machine, assembly and  
 shipping.

In the machine system, consideration is given to the fact of using  
 machine tools, however, in order to give the machine a machine  
 as a machine. In this way, machine, assembly, a very important part  
 time in the machine system, can be said to be.

### Machine System

The machine system, which is the same as the machine system,  
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 the or the machine system, which is the same as the machine system.

These machine tools represent the greater part of a work, and  
 can be said to be the machine system, which is the same as the machine system,  
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 the or the machine system, which is the same as the machine system,  
 the or the machine system, which is the same as the machine system,  
 the or the machine system, which is the same as the machine system.

(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15)



### Machine Movability

Machine movability is the capacity of machines to be moved without undue effort, cost, or waste of time. It implies the mere setting of machines on the floor without cementing in and/or bolting down.

It is particularly desirable in intermittent and in continuous manufacturing plants where there are periodic model changes in the manufactured product to have plant machinery readily movable. For example, the Spicer Manufacturing Company of Toledo once moved an average of twenty machines per week. Machine movability requires adequate plug-ins for electricity and adequate compressed air, water, and sewage connections. In addition, machines must be provided with their own transformers, controllers, and flexible cable connections.

(2, 19, 21, 22, 37, 38, 39, 53, 55, 56, 62, 63)

### Floor Space

In speaking of plant floor space, we mean the floor area which is housed in that part of the plant devoted to production installations.

Floor space, since it is inside a building by definition, is costly and should therefore be conserved. There are two avenues open leading to space conservation. One is arranging machinery compactly while the other is elimination of unnecessary aisles. In some peculiar western plants, the plant floors are not roofed over. Necessarily the same principles apply.

(2, 10, 11, 18, 19, 20, 22, 28, 32, 35, 44, 50, 58)

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## Number of Stories

The number of stories here referred to is that in the plant proper where production facilities are housed.

There are advantages to be found in one story plant buildings and in multi-story buildings. The usual ones listed are:

### Single Story.

1. Easy to expand by additions.
2. Heavy floor loading possible throughout plant.
3. Easier foundation requirements.
4. More natural light and air available.
5. Easy to rearrange layout of plant.
6. No floor space wasted on elevators and stairs.
7. Materials handling costs are less.
8. Lower cost per square foot of floor area.

### Multi-Story.

1. Smaller area of land used.
2. Cheaper to heat.
3. Lower building maintenance cost.
4. Use of gravity feed allowed.
5. Upper stories free of dirt and street noise.
6. Easier to build on a hill side.

(2, 4, 10, 11, 19, 20, 22, 33, 34, 35, 36, 37, 39, 58, 60)

Number of stories

The number of stories here referred to is that in the ground story

where production facilities are located.

There are advantages to be found in one story plant buildings and

in multi-story buildings. The latter are listed as:

Multi-story.

1. They are erected by addition.
2. Heavy floor loading possible throughout plant.
3. Greater foundation requirements.
4. More natural light and air available.
5. Easy to remove layers of plant.
6. No floor space wasted on elevators and stairs.
7. Materials handling costs are less.
8. Lower cost per square foot of floor area.

Single-story.

1. Smaller area of land used.
2. Cheaper to heat.
3. Lower building maintenance cost.
4. Use of gravity feed allowed.
5. Greater storage room of dirt and street noise.
6. Easier to build on a hill side.

(2, 4, 10, 11, 17, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30)



## THE PROPOSAL OF CRITERIA

From a consideration of the foregoing review of literature, the following eleven indices are proposed as factors of importance in plant layout. Since they are measurable and in all respects readily obtainable, they are herewith offered as criteria for evaluating physical-plant utilization. An effort has been made to arrange or weight the factors of each of the first ten indices in such a manner that their individual calculated values will be fractional, approaching unity as maximum. The eleventh index will invariably be greater than unity.

It will be readily apparent to industrial engineers that all of the following proposed indices do not necessarily apply to any given industrial layout. It is believed, however, that all of them could apply to some layouts, and that most of them will apply to most layouts.

### 1. Index of Indirect Materials Handling = $\frac{a}{b}$

where a = The sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling

and b = The total actual distance a part moves via the production route from raw stores to finished stores

The fact that materials handling costs are losses and the recommended methods for eliminating them suggested this index, since it measures the ratio of the distance a production part moves automatically to the total distance the part moves.

In the numerator of the formula, the term "external materials handling" is construed to mean movement of production materials in boxes from one location to another by any person, whether he be a machine operator or a materials handling employee. The denominator represents the total distance

[illegible]

It will be readily apparent to industrial engineers that all of the following provisions herein do not necessarily apply to all types of machinery. It is believed, however, that all of them would apply to some type of machinery.

## Index of Subject Categories: 5

Figure 2. The use of the distal end of the mandible as a lever for the tongue and lips in the mandible.

TABLE 1. The effect of the type of the substrate on the growth of the *Trichoderma reesei* on the substrate.

The fact that multiple travelling waves are observed and the corresponding methods for identification that suggested this paper, show it deserves the title of the distance & position of the wave automatically to the total distance of the wave.

is contained in some element of  $\mathcal{P}$  and  $\mathcal{P}$  is a partition of  $\mathcal{P}$ . The decomposition represents the total distance between the points in  $\mathcal{P}$  and  $\mathcal{P}$  as a sum of distances between the points in  $\mathcal{P}$  and  $\mathcal{P}$ . The decomposition represents the total distance between the points in  $\mathcal{P}$  and  $\mathcal{P}$  as a sum of distances between the points in  $\mathcal{P}$  and  $\mathcal{P}$ .



a part moves in the production process from raw stores to the first operation station, from there to the next, and so on, until it reaches finished stores.

The formula was placed in this form because the index value approaches one as external materials handling is reduced.

The index becomes a criterion of plant layout because it is a measure of the efficiency of the elimination of materials handling from particular production paths. A high index value indicates that a part moves through the production process mostly by conveyors, chutes, or common finished parts - raw parts locations, while a low value indicates that the part is mostly moved by non-producing personnel.

$$2. \text{ Index of Direct Materials Handling} = \frac{c}{b}$$

where  $c$  = The direct line distance via the plant floor from raw stores to finished stores

and  $b$  = The total actual distance a part moves via the production route from raw stores to finished stores

This index was suggested by the same considerations as was the previous index. It should be noted that the Index of Indirect Materials Handling deals with the efficiency with which a production route is covered while the Index of Direct Materials Handling is concerned with how that route is laid out.

The numerator of the formula is intended to be the straight-line measure of distance from raw stores to finished stores by way of the plant floor. Where materials enter at one end of the building and emerge at the other, it will be the straight through distance. For an L-shaped plant, it will be the L distance and so on. The denominator is merely the measure of the complete length of the actual production path.

The formula was arranged in its particular form because its theoretical maximum approaches unity.



a part away in the direction of the front of the  
the section, from front to back, and so on, until it reaches the  
front.

The formula was given in this form because the index value approaches  
one as the actual distance becomes small.

The index becomes a criterion of the relative distance in a manner  
of the efficiency of the utilization of the actual distance. The formula  
indicates that a high index value indicates that a part is more

the production process is mostly by conveyor, shovel, or other limited paths -  
the parts themselves, while a low index indicates that the part is mostly  
moved by non-productive personnel.

2. Index of Direct Material Handling =  $\frac{2}{3}$   
where  $\frac{2}{3}$  = The direct line distance to the point from the  
store to the point.

and  $\frac{2}{3}$  = The actual distance a part moves to the  
actual point from the store to the point.

This index was suggested by the same consideration as was the previous  
index. It should be noted that the index of direct material handling is  
with the efficiency with which a production route is chosen while the index  
of direct material handling is concerned with the route itself.

The numerator of the formula is identical to the straight-line  
measure of distance from the store to the point as by way of the first  
floor. There details must be one end of the building and store at the  
other, it will be the actual distance. For an example, if  
will be the distance and so on. The denominator is merely the square of  
the coefficient of the actual production route.

The formula was suggested in the previous form because the theoretical  
maximum approaches unity.

For the denominator to be reduced to a value near that of the numerator of the formula, the machines of a plant, will, of necessity, have to be arranged in operation sequence from raw stores in a direct line toward finished stores, thus eliminating external materials handling.

The above index is, therefore, considered a criterion of efficient plant layout since it is a measure of the efficiency with which the production route covers the distance from raw to finished stores.

### 3. Index of Gravity Utilization = $\frac{d}{e}$

where d = The sum of the vertical distance gravity feed used

and e = The total vertical distance up a part moves from raw stores to finished parts

The suggestion of using gravity as a conveyor actuator under materials handling in the review of literature suggested the index of gravity utilization.

Ideally, a part lifted up from the main floor of the plant should be returned thereto alone by the force of gravity without having to expend further materials handling in the process. Should this obtain, the value of the above index approaches one.

The above index is offered as a criterion of plant layout because it measures the efficiency with which gravity is used in returning to the main floor parts lifted therefrom.

### 4. Prime Index of Automatic Machinery Loading = $\frac{f}{100g}$

where f = The sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles

and g = The total number of operators on those machines

This index was suggested by the subject of multi-machine operation.

For the dimension to be reduced to a value less than that of the dimension of the domain, the dimension of a group, with all necessary, must be changed in several dimensions from the value to a value less than the dimension of the domain, with all necessary, must be changed.

The above index is, therefore, considered a measure of efficiency. The index is the measure of the efficiency with which the dimension of the domain is reduced from the value to a value less than the dimension of the domain.

### 1. Index of Efficiency Reduction = $\frac{1}{2}$

where  $\frac{1}{2}$  = the value of the domain dimension, from the value to a value less than the value of the domain dimension, from the value to a value less than the value of the domain dimension.

The reduction of index, from the value of the domain dimension, from the value to a value less than the value of the domain dimension, from the value to a value less than the value of the domain dimension.

Index, a value less than the value of the domain dimension, from the value to a value less than the value of the domain dimension, from the value to a value less than the value of the domain dimension.

The above index is, therefore, considered a measure of efficiency. The index is the measure of the efficiency with which the dimension of the domain is reduced from the value to a value less than the value of the domain dimension.

### 2. Index of Efficiency Reduction = $\frac{1}{3}$

where  $\frac{1}{3}$  = the value of the domain dimension, from the value to a value less than the value of the domain dimension, from the value to a value less than the value of the domain dimension.

The above index is, therefore, considered a measure of efficiency. The index is the measure of the efficiency with which the dimension of the domain is reduced from the value to a value less than the value of the domain dimension.



By down time is meant the portion of the work cycle where the machine is unloaded and reloaded in the manner that an automatic lathe would be. This index can be used only for machinery where the machine time portion of the over-all work cycle is automatic and the machines may be left unattended while operating. The factor of 100 was placed in the denominator to preserve the fractional value because the numerator is the sum of percentages.

The above index measures the efficiency of grouping machines for multi-machine operation and is, therefore, considered a criterion of good layout. If there are too many operators for the machines, the index value will be low and will increase as more machines are operated by fewer operators. Note that only machines with 50 percent down time or less are used, since these offer an easier opportunity for grouping and it was desired to have this index measure, on a large scale, the effectiveness with which this was done.

$$5. \text{ Secondary Index of Automatic Machinery Loading} = \frac{h}{100g}$$

where  $h$  = The sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of the individual work cycles

and  $g$  = The total number of operators on those machines

This is a measure of the success of solving the more difficult problem of grouping machines whose down time is such as to create the need for odd combinations of machines and men.

$$6. \text{ Index of Flexibility} = \frac{j}{k}$$

where  $j$  = The number of machines capable of being moved to a new location in the production line in one working shift

and  $k$  = The total number of machines in the production line

Index of flexibility was suggested by consideration of the desirable features of having machines readily movable.

It was also to count the number of the birds which were the subject of the study. The birds were numbered by the number of the bird which was the subject of the study. The birds were numbered by the number of the bird which was the subject of the study.

The above facts demonstrate the efficiency of the proposed method for the machine operation and its, therefore, considered a description of good design. It shows that the proposed method for the machine, the same value will be low and will increase as more machines are operated by these systems. This fact only machine with 50 percent down time or less are used time limit often an easier opportunity for trading and is now desired to have this index measure as a large scale, the efficiency with which this can be done.

$$-\frac{1}{\sigma^2} = \frac{1}{\sigma^2} \left( \frac{1}{\sigma^2} + \frac{1}{\sigma^2} \right) = \frac{1}{\sigma^2} + \frac{1}{\sigma^2}$$

There is a large number of small, scattered, and isolated islands in the area, and the total area of the islands is about 100,000 square miles. The islands are mostly small, and the total area of the islands is about 100,000 square miles. The islands are mostly small, and the total area of the islands is about 100,000 square miles.

This is a measure of the success of solving the two difficult cases of grouped variables whose data is such as to create the need for the use of the two cases.

1. a.  $\frac{1}{2}$  b.  $\frac{1}{2}$  c.  $\frac{1}{2}$  d.  $\frac{1}{2}$  e.  $\frac{1}{2}$

1. The number of members of the committee is 10.

and the total number of stations in the formation line

Approved and for transmission of information was published 23.02.2015

Features of the system include:



The components of the formula are self-explanatory.

Since the index measures the fraction of the total number of machines readily movable in a plant, it here is offered as a criterion of plant layout.

$$7. \text{ Index of Floor Area Loading Density} = \frac{\sum [(m + 2)(n + 2) + p]}{q - r}$$

where  $m$  = Extreme machine length in feet

$n$  = Extreme machine width in feet

$p$  = Operator work area in square feet

$q$  = Total plant floor area in square feet

and  $r$  = Total aisle area in square feet

This index was suggested by consideration of the floor space conservation suggestion of the literature dealing with compact machinery arrangement on the plant floor.

A glance at the numerator of the formula reveals that it is the sum of the profile areas of machines as viewed from above with a one-foot wide clear space around each and with the operator work spaces added in. The one-foot clear space is provided as an addition to the profile areas by necessity since common practice allows at least two feet between adjacent machines for their servicing. The term machines in the formula includes all production machinery including conveyors that rest on or near the floor but excludes overhead conveyors which pass over and clear of other machinery. The denominator of the formula is the sum of the floor area of the plant available for the locating of machinery. Aisles are excluded from available plant floor area by definition and are treated in the index following.

The formula is arranged in its above form so that a heavy floor loading density will give a greater index value than a light loading, and also, an index value of one represents perfect floor area loading.



The formula for the formula is self-explanatory.  
 Since the index number is the ratio of the total number of machines  
 actually present in a plant, it must be observed as a condition of plant layout.

$$I = \frac{[ (L + 5) (L + 5) + 5 ]}{P}$$

- where  $L$  = distance machine length in feet
- $P$  = distance machine width in feet
- $5$  = Operator work area in square feet
- $I$  = Total plant floor area in square feet
- and  $T$  = Total plant area in square feet

This index was suggested by consideration of the floor space requirements  
 suggested by the literature dealing with layout problems arranged on  
 the plant floor.

A glance at the numerator of the formula reveals that it is the sum of  
 the profile areas of machines as viewed from above with a one-foot wide  
 clear space around each and with the operator work space added in. The  
 one-foot clear space is provided as an addition to the profile areas of  
 machines since common practice allows at least one foot between adjacent  
 machines for their servicing. The work machines in the formula includes  
 all production machinery including conveyors that rest on or near the floor  
 but excludes overhead conveyors which pass over and clear of other machinery.  
 The denominator of the formula is the sum of the floor area of the plant  
 available for the location of machinery. Areas are excluded from avail-  
 able plant floor area by definition and are viewed in the index following.  
 The formula is arranged in its above form so that a heavy floor  
 loading heavily will give a greater index value than a light loading, and  
 also, an index value of one represents perfect floor area loading.

The index, as calculated by the formula, is offered as a criterion because it represents a measure of the efficiency with which the plant floor area is used. A high value of the index results from close, compact arrangement of machinery, while a low value indicates loose and spread out spacing.

$$8. \text{ Index of Aisle Wastage} = \frac{q - r}{q}$$

where  $q$  = Total plant floor area

and  $r$  = Total aisle area

This index was suggested by consideration of floor space conservation through elimination of unnecessary aisles.

Aisle area represents floor area not available for active production and is, therefore, an item to be minimized.

Since the index yields a value representing the fractional part of the total plant floor area available for placement of production machinery, it is here considered a criterion of plant layout.

$$9. \text{ Time Index} = \frac{s}{t}$$

where  $s$  = The sum of the standard times for all operations on a part

and  $t$  = The total standard times for the part, raw stores to finished stores including handling time and time in banks

This index was not suggested by any specific principle of plant layout, rather it was conceived from an understanding of the general problems of plant layout.

The numerator of the formula, being the sum of the standard time for operations on a part, represents the total time the part should be actively worked on in production. The denominator yields the total time the part should be in process from start to finish of the production process. Note that standard times are used. This eliminates consideration of operator

The index is calculated by the formula, as shown in a typical example, because it represents a measure of the efficiency with which the plant uses its water. A high value of the index means that the plant is efficient in its use of water, while a low value indicates that the plant is not efficient.

$$A. \text{ Index of plant efficiency} = \frac{W - E}{W}$$

where  $W$  = Total plant flow rate

and  $E$  = Total water loss

This index was suggested by consideration of the above considerations through elimination of unnecessary items. Also one important factor was not available for simple presentation and is, therefore, as far as possible, omitted.

Since the index yields a value representing the efficiency of the total plant flow rate available for process of treatment, it is here considered a criterion of plant layout.

$$B. \text{ Cost Index} = \frac{C}{W}$$

where  $C$  = The cost of the water supply for all operations on a plant

and  $W$  = The total amount of water for the year, as shown in Table 1, which shows the total water supply for the year.

This index was not suggested by any specific principle of plant layout, but it was suggested from an understanding of the general problem of plant layout.

The number of the formula, being the sum of the number of the operation on a plant, represents the total time the plant should be used in its operation. The number of the total time the plant should be in service from start to finish of the production process. This should be the total. This eliminated consideration of operation



efficiency and reduces the index to a function solely of a plant layout.

The formula was placed in the above form in order that its maximum value could approach unity.

Materials handling and the banking of parts while in production are plant layout problems. Since this index measures the time efficiency with which a part traverses the production process, it is offered here as a plant layout criterion. A low index value indicates that a part wastes time idling in temporary storage along the production process (a high in process inventory value) while a high index value indicates that the part moves smoothly and steadily along the production route, (a low in process inventory value).

$$10. \text{ Index of Human Comfort} = \frac{u + v + w}{3}$$

where  $u$  = Factor from Table 1

$v$  = Factor from Table 2

and  $w$  = Factor from Table 3

Table 1

Operator Work Space

Smallest Dimension of Available  
Area in which Operator Performs  
His Work

	Factor
30 inches and above	1.00
29 inches	.90
28 inches	.80
27 inches	.70
26 inches	.60
25 inches	.50
24 inches	.40
23 inches	.30
22 inches	.20
21 inches	.10
20 inches and below	0.0



The former life of the latter is not the same as the former life of the latter.

that some monetary policy along the production curve, (a low in process inventory value) while a high index value indicates that the firm is in a position to expand its production process, it is often used as a guide to the firm's position. Since this index measures the firm's efficiency with respect to its production and the amount of time which is required to

$$\frac{N_1 + \tau_1 + \tau_2 + M}{\delta} = 1.75 \times 10^6 \text{ mm}^2 \text{ to design } \quad (11)$$

I will not make a

1. *et al.*

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Table 2

## Work Place Temperature

Degrees Fahrenheit	Factor
110° and above	.0
105°	.10
100°	.25
95°	.50
90°	.70
85°	.80
80°	.90
75°	.95
70°	1.00
65°	.90
60°	.80
55°	.60
50°	.40
45°	.20
40° and below	.00

Table 3

## Lighting of Work Area

Foot Candles for Occupations A-E as Listed Below					Factor
A	B	C	D	E	
5	10	20	55	100 and above	1.00
4	8	17	45	85	.75
3	6	14	35	70	.50
2	4	11	25	55	.25
1	2	8	15	40 and below	.00

- A. Warehouses, aisles, stairways, passageways.
- B. Rough assembly, general indoor construction, grinding, locker rooms, glass blowing, plating, power plants, elevators.
- C. General manufacturing, textile mills, machine shops, fine assembly, bakeries, canning, general painting, polishing, proof reading, class rooms, general offices.
- D. Extra fine grading and sorting, cutting, polishing and inspecting glass, offices doing fine work, drafting rooms.
- E. Extra fine assembly such as jewelry, watch and instrument making, dark goods manufacture, extra fine machine work, engraving, linotype, monotype.



The Index of Human Comfort was not conceived by any special regard for plant layout principles. Numerous volumes, however, have been written on the subject of employer-employee relationships which discuss at length the fact that industry of today, to survive, must consider labor to consist of fellow human beings rather than to exist as a commodity. Of all of management's complex problems in dealing with labor one falls directly upon the layout engineer. That is the layout of the worker's work area. There are three fundamental components thereof. They are the physical area in which a worker is confined in performing his tasks, the light which he has to work by, and the temperature of the area in which he works. Factor values were assigned in Tables 1, 2 and 3 above in accordance with previously determined standards.

$$11. \text{ Inventory Index} = \frac{x}{y}$$

where  $x$  = The rate of production

and  $y$  = Time index

This index does not approach unity as a maximum. It measures the number of production units planned for the production line at any one time. It is offered here as being of use since any materials tied up in the process of production represent an investment, sometimes costly, from which no returns are realized. Every effort should be made to reduce to absolute minimum the "in production inventory".

Reviewing the components of the preceding eleven indices it is readily apparent that they are easily obtainable and measurable quantities. They are:



[illegible][illegible]

1. The first of these is the fact that the majority of the population of the United States is now living in urban areas. This is a result of the process of urbanization, which has been going on since the beginning of the 20th century. The process of urbanization is the movement of people from rural areas to urban areas. This is a result of the fact that urban areas offer more opportunities for employment and education. The process of urbanization has led to the growth of large cities and the decline of small towns. This has led to a concentration of population in a few large urban areas. This concentration of population has led to a number of problems, including traffic congestion, air pollution, and the loss of open space. The second of these factors is the fact that the majority of the population of the United States is now living in the South and West. This is a result of the process of migration, which has been going on since the beginning of the 20th century. The process of migration is the movement of people from one part of the country to another. This is a result of the fact that the South and West offer more opportunities for employment and education. The process of migration has led to the growth of large cities in the South and West and the decline of small towns in the North and East. This has led to a concentration of population in a few large urban areas in the South and West. This concentration of population has led to a number of problems, including traffic congestion, air pollution, and the loss of open space. The third of these factors is the fact that the majority of the population of the United States is now living in the Northeast. This is a result of the process of migration, which has been going on since the beginning of the 20th century. The process of migration is the movement of people from one part of the country to another. This is a result of the fact that the Northeast offers more opportunities for employment and education. The process of migration has led to the growth of large cities in the Northeast and the decline of small towns in the South and West. This has led to a concentration of population in a few large urban areas in the Northeast. This concentration of population has led to a number of problems, including traffic congestion, air pollution, and the loss of open space.

• 1975-1976

- a - The sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling
- b - The total actual distance a part moves via the production route from raw stores to finished stores
- c - The direct line distance via the plant floor from raw stores to finished stores
- d - The sum of the vertical distance gravity feed used
- e - The total vertical distance up a part moves from raw stores to finished parts
- f - The sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles
- g - The total number of operators on those machines
- h - The sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of the individual work cycles
- j - The number of machines capable of being moved to a new location in the production line in one working shift
- k - The total number of machines in the production line
- m - Extreme machine length in feet
- n - Extreme machine width in feet
- p - Operator work area in square feet
- q - Total plant floor area in square feet
- r - Total aisle area in square feet
- s - The sum of the standard times for all operations on a part
- t - The total standard times for the part, raw stores to finished stores including handling time and time in banks
- u - A tabled area factor value
- v - A tabled temperature factor value
- w - A tabled lighting factor value
- x - The rate of production
- y - Time index

- 1 - The rate of production
- 2 - A labeled lighting factor value
- 3 - A labeled temperature factor value
- 4 - A labeled area factor value
- 5 - The total upward time for the heat ray shown in Figure 1, including building time and time in tanks
- 6 - The sum of the upward times for all rays shown in a box
- 7 - Total area time in square feet
- 8 - Total floor area in square feet
- 9 - Upward area time in square feet
- 10 - Surface area time in square feet
- 11 - Volume surface time in feet
- 12 - The total weight of material in the production line
- 13 - The number of machines capable of being moved to a new location in the individual work cycles
- 14 - The sum of the percentages of material down time for all areas where the individual percentages of down time are equal to or less than 10% of the individual work cycles
- 15 - The total number of operators on these machines
- 16 - The sum of the percentages of material down time for all areas where the individual percentages of down time are greater than 10% of the individual work cycles
- 17 - The total vertical distance of a part across the work area in inches
- 18 - The sum of the vertical distances gravity feed parts
- 19 - The direct line distance with the flow from one station to the next
- 20 - The total number of parts across a part across the production route from the start of the building
- 21 - The sum of the distances of each machine in the building



## APPLICATION OF CRITERIA TO EXISTING PLANT

In searching for a plant to which to apply the developed criteria of effective plant layout, a small, newly formed plant in west central Indiana was chosen. It is a plant that began production of tub, basin and sink valve fixtures only recently. Starting with five employees the plant has mushroomed without benefit of layout techniques to where it now employs fifty people.

Not long ago the plant made some changes in layout in an effort to adopt some recommended methods and layout improvements. Figure 1 is a photograph of a block template layout before the change and Figure 2 that after the change.







Fig. 1 Template Layout of Plant, Initial Layout

1941

1941

1941

1941

1941

1941

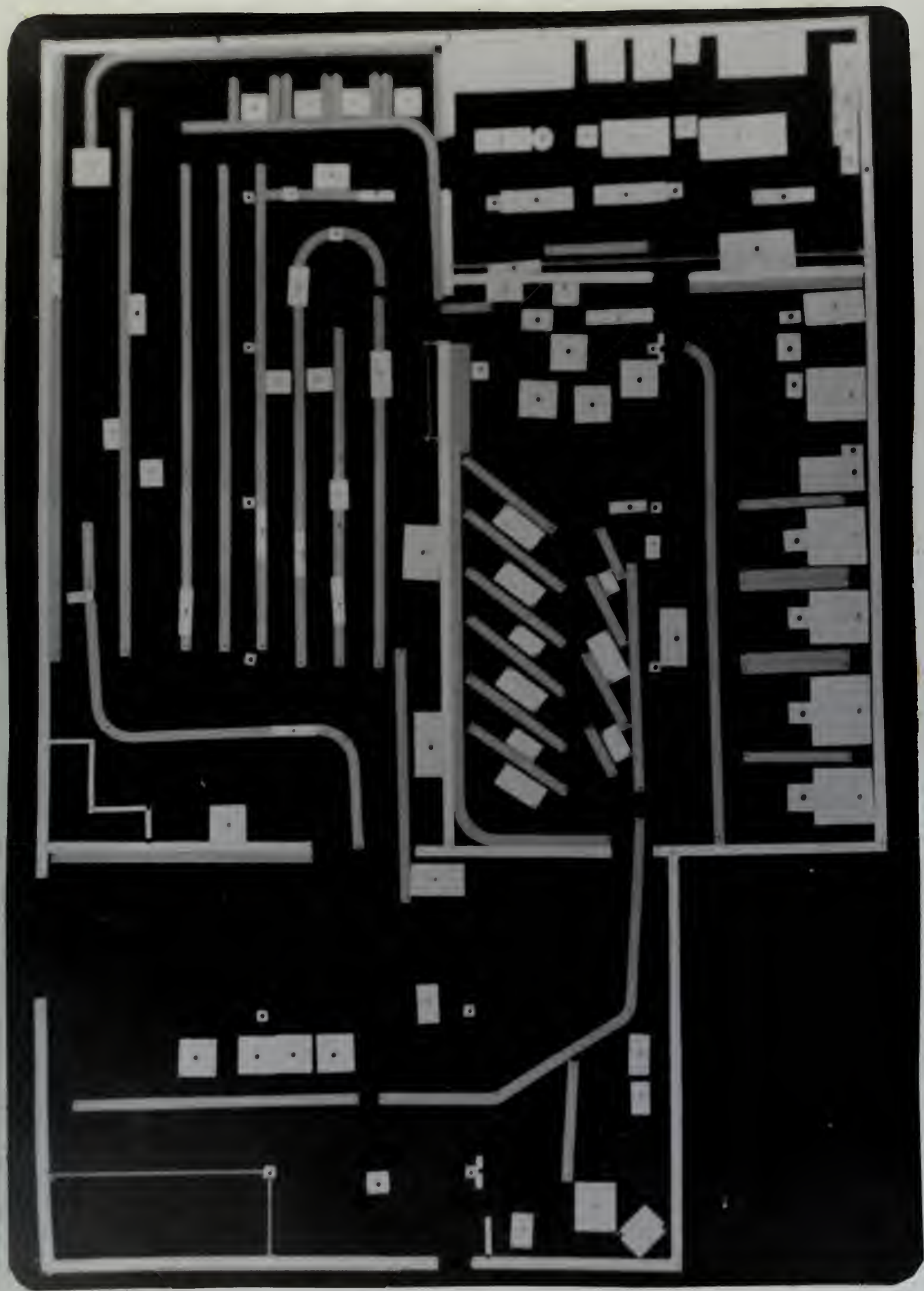








Fig. 2 Template Layout of Plant, Improved Layout



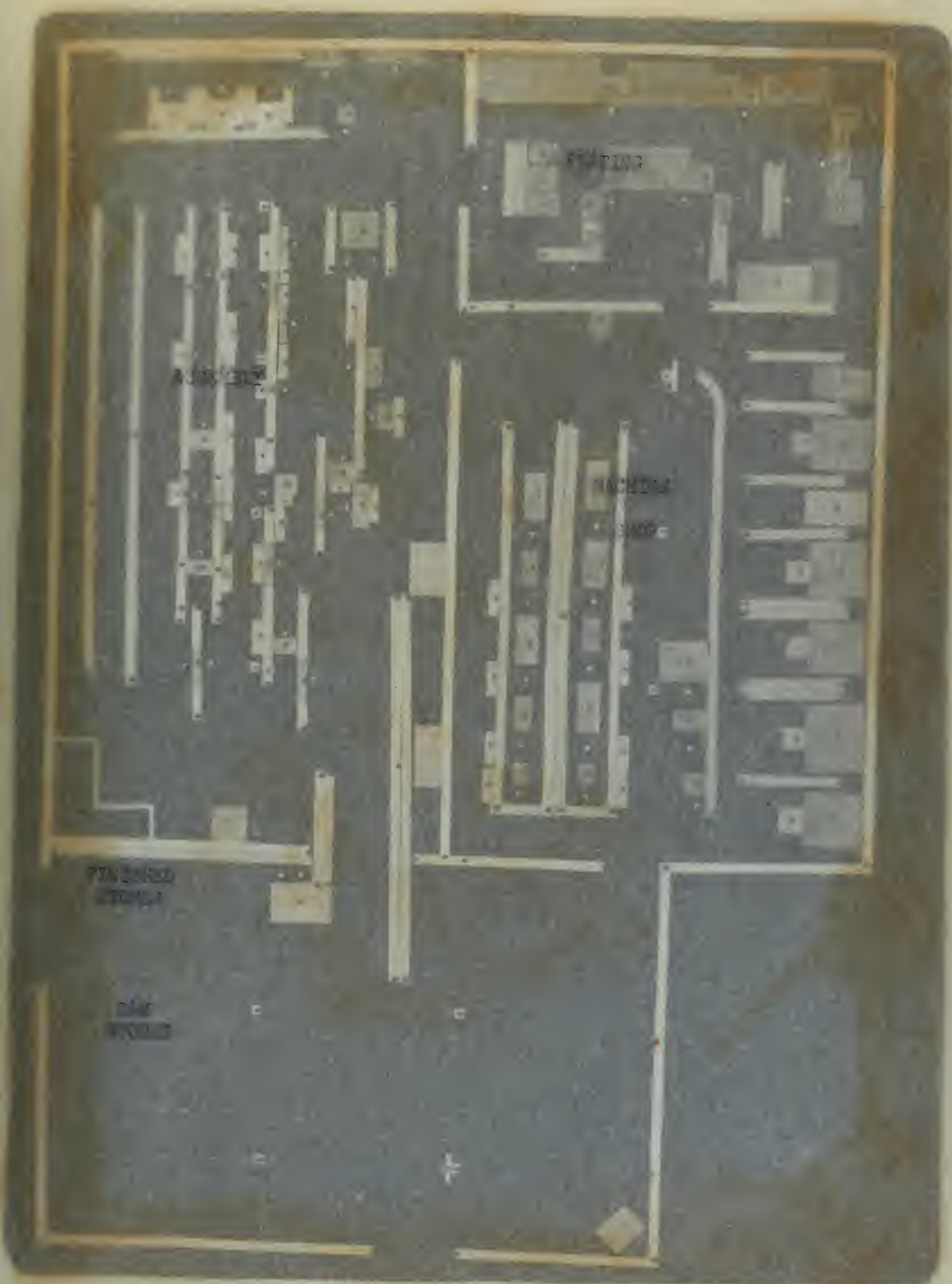


Fig. 2 Template Layout of Plant, Improved Layout



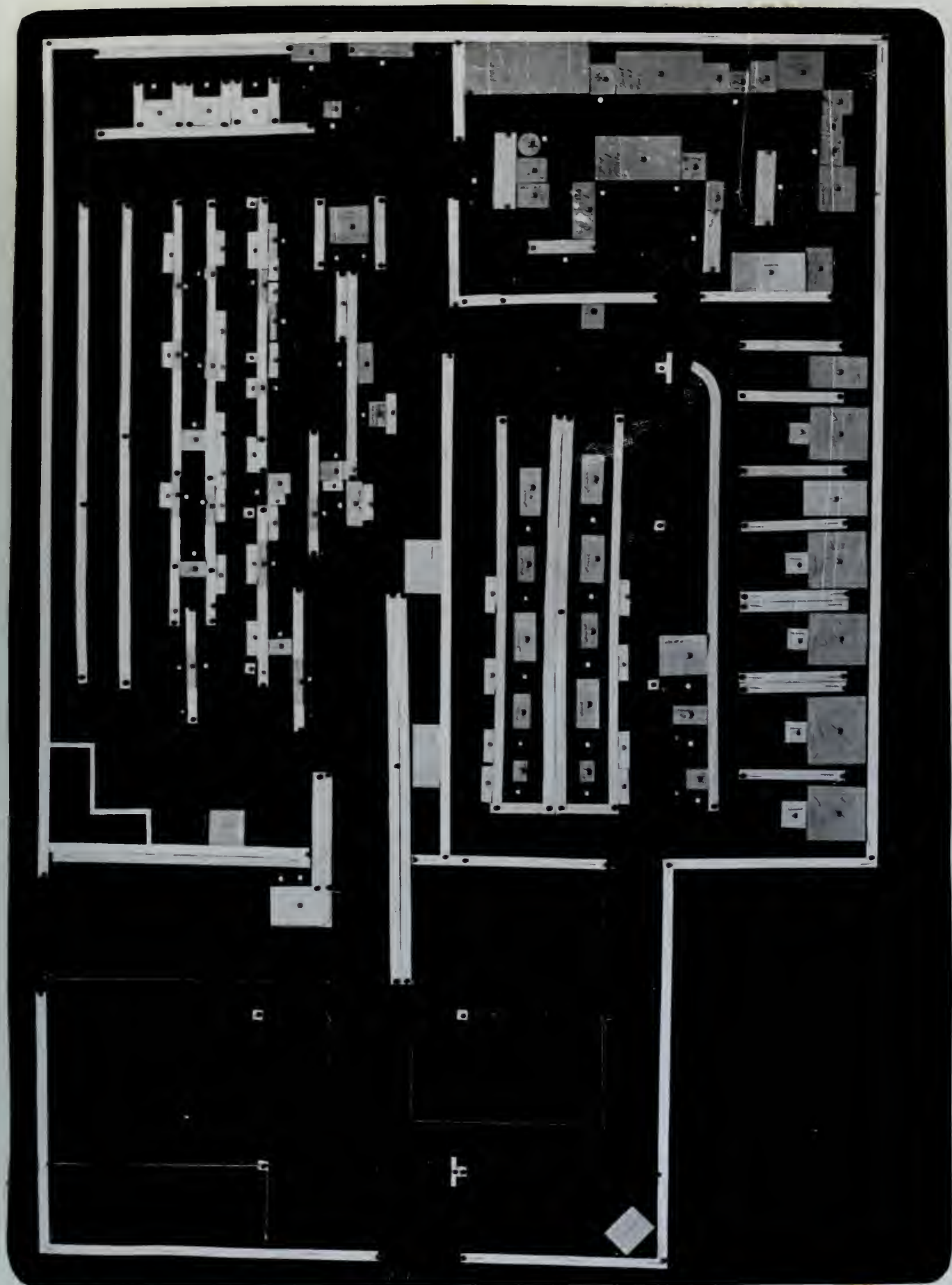
Station

Topographic map

Station

Topographic map

Station





Two valves, numbers 308 and 280 were chosen as typical production because these two comprise approximately 80% of total production. Criteria measurements were made before and after the layout changes and, where different, they appear below in the computation of indices.

$$1. \text{ Index of Indirect Materials Handling} = \frac{a}{b}$$

where a = The sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling

and b = The total actual distance a part moves via the production route from raw stores to finished stores

Initial Layout		Changed Layout	
Valve 308	a = 0	a = 42 ft.	
	b = 343 ft.	b = 264 ft.	
Index	$= \frac{0}{343} = 0$	Index	$= \frac{42}{264} = .16$
Valve 280	a = 0	a = 40 ft.	
	b = 576 ft.	b = 303 ft.	
Index	$= \frac{0}{576} = 0$	Index	$= \frac{40}{303} = .13$

Valves 308 and 280 consist of many parts, but the main part, however, is the valve body which passes along the complete production line and is joined at various points along the line by the other parts. Quantities a and b were therefore measured for the valve body from raw stores through the production route, including assembly of all other parts to the body, and on until the finished valve was packaged and delivered to finished stores.

Although several hundred feet of roller conveyors were installed in the plant, they were not used initially for the usual purpose intended, and much of the conveyor length was used for storage of parts. The change in



The valve, number 305 and 306 were shown in typical condition.

Because these two valves are approximately 50% of total production, typical

measurements were made before and after the repair through this valve.

different, they appear below in the comparison of figures.

$$1. \text{ Index of delivery, relative formula: } \frac{A}{B}$$

where  $A$  = The sum of the distances a part moves automatically  
in conveyor and from machine to machine required to  
operate; and  $B$  = The sum of the distances a part moves manually.

and  $B$  = The total actual distance a part moves via the  
conveyor from raw material to finished goods.

Typical layout

$$\begin{aligned} A &= 42.17 \\ B &= 30.17 \\ \text{Index} &= \frac{42.17}{30.17} = 1.39 \end{aligned}$$

$$\begin{aligned} A &= 42.17 \\ B &= 30.17 \\ \text{Index} &= \frac{42.17}{30.17} = 1.39 \end{aligned}$$

Typical layout

$$\begin{aligned} A &= 0 \\ B &= 30.17 \\ \text{Index} &= \frac{0}{30.17} = 0 \end{aligned}$$

$$\begin{aligned} A &= 0 \\ B &= 30.17 \\ \text{Index} &= \frac{0}{30.17} = 0 \end{aligned}$$

Valve 305 and the opening of each valve, and the main part, number

is the valve body which passes along the complete production line and is

joined at various points along the line by the other valves. Condition

A and B were therefore measured for the valve body from raw material through

the production route, including assembly of all other parts to the body.

and on until the finished valve was packaged and delivered to finished goods.

Although several hundred feet of roller conveyor were installed in

the plant, they were not used initially for the small volume product, and

and of the conveyor layout was used the majority of parts. The change in

layout included slanting some sections of the conveyor thus providing real values for quantity a. Throughout the rest of the distance operators stop working to move materials from station to station.

## 2. Index of Direct Materials Handling = $\frac{c}{b}$

where c = The direct line distance via the plant floor from raw stores to finished stores

and b = The total actual distance a part moves via the production route from raw stores to finished stores

Initial Layout		Changed Layout	
Valve 308	c = 216 ft.	c = 216 ft.	
	b = 343 ft.	b = 264 ft.	
Index	$= \frac{216}{343} = .63$	Index = $\frac{216}{264} = .82$	
Valve 280	c = 216 ft.	c = 216 ft.	
	b = 576 ft.	b = 303 ft.	
Index	$= \frac{216}{576} = .38$	Index = $\frac{216}{303} = .71$	

As in the preceding index, valve body travel distances were used in measuring quantity b. Quantity c was measured from raw stores through the machine shop in a straight line, on into and through assembly in an L path and on to finished stores.

The increases of the index in the changed layout reflects the shortened production route established by the change.

## 3. Index of Gravity Utilization = $\frac{d}{e}$

where d = The sum of the vertical distance gravity feed used

and e = The total vertical distance up a part moves from raw stores to finished parts

Initial Layout		Changed Layout	
Valve 308 and 280	d = 0	d = 2	
	e = 7½	e = 7½	
Index	$= \frac{0}{7\frac{1}{2}} = 0$	Index = $\frac{2}{7\frac{1}{2}} = .27$ approx.	





In the initial layout quantity d was zero, but it has a real value in the new layout because of the tilting of the roller conveyors to provide automatic materials handling. The valve materials are lifted to roller conveyor height once going into the machine shop and once going into assembly.

$$4. \text{ Prime Index of Automatic Machinery Loading} = \frac{f}{100} g$$

where f = The sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles

and g = The total number of operators on those machines

This index and the one following have no value because the plant under consideration has no automatic machinery.

$$5. \text{ Secondary Index of Automatic Machinery Loading} = \frac{h}{100} g$$

where h = The sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of the individual work cycles

and g = The total number of operators on those machines

$$6. \text{ Index of Flexibility} = \frac{j}{k}$$

where j = The number of machines capable of being moved to a new location in the production line in one working shift

and k = The total number of machines in the production line

Initial and Changed Layout

$$\begin{aligned} j &= 35 \\ k &= 48 \\ \text{Index} &= \frac{35}{48} = .73 \end{aligned}$$

The plant surveyed has a total of 48 machines of which 13 are fixed and 35 are capable of being moved. The index has the same value for both layouts because the change did not alter the machinery equipment of the plant.



[illegible]

$$\frac{2}{100} = \text{Price Index of Domestic Products} = 102$$

1. The first of the two main types of the  
2. second type is the "simple" type, which  
3. is characterized by a single, unbroken  
4. line of the "simple" type, which is  
5. characterized by a single, unbroken  
6. line of the "simple" type, which is  
7. characterized by a single, unbroken  
8. line of the "simple" type, which is  
9. characterized by a single, unbroken  
10. line of the "simple" type, which is

of the last wave of operators in this chain

With today and the one following being no wine because the *Yom Kippur* holiday.

Downloaded At: 11:53 11 September 2009

2.  $\lim_{x \rightarrow 0} \frac{1}{x} = \infty$  (or  $-\infty$ )

There are two groups of individuals who are not included in the sample. First, individuals who are not in the sample are those who are not in the sample. Second, individuals who are not in the sample are those who are not in the sample.

and a 100% increase in the number of observations in 1994.

$$x = \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$$

where  $\beta$  is the number of samples capable of being stored in the processor in the production line in one working shift.

and  $\lambda = 0.01$  (upper left) and  $\lambda = 0.05$  (upper right) are shown. The lower panels show the results for  $\lambda = 0.01$  (lower left) and  $\lambda = 0.05$  (lower right) for the same two cases. The results for  $\lambda = 0.01$  are shown in the left column and for  $\lambda = 0.05$  in the right column. The results for  $\lambda = 0.01$  are shown in the left column and for  $\lambda = 0.05$  in the right column. The results for  $\lambda = 0.01$  are shown in the left column and for  $\lambda = 0.05$  in the right column.

$$CV = \frac{22}{70} = 0.314$$

The first company for a total of 12 machines at which it was found that it was capable of being used. The machine was the same value for both parties.

$$7. \text{ Index of Floor Area} = \frac{\sum [(m + 2)(n + 2) + p]}{q - r}$$

Loading Density

where  $m$  = Extreme machine length in feet

$n$  = Extreme machine width in feet

$p$  = Operator work area in square feet

$q$  = Total plant floor area in square feet

$r$  = Total aisle area in square feet

Initial Layout

$$\text{Index} = \frac{3350.5}{5142} = .65$$

Changed Layout

$$\text{Index} = \frac{3208.5}{4712} = .68$$

In the interest of presenting only figures of importance herein, the individual values of  $m$ ,  $n$ ,  $p$ ,  $q$  and  $r$  are not listed. Several pages would be required to record all their values since there are a total of 48 machines and many aisles.

It is to be noted that the new layout has reduced the value of the numerator of the index formula. This was caused by the elimination of unnecessary roller conveyor. Also note that the denominator of the new layout index has been reduced. The new layout spaced the lines more compactly and thus opened up more area which for lack of better use exists as aisles.

$$8. \text{ Index of Aisle Wastage} = \frac{q - r}{q}$$

where  $q$  = Total plant floor area in square feet

and  $r$  = Total aisle area in square feet

Initial Layout

$$\begin{aligned} q &= 6400 \text{ sq. ft.} \\ r &= 1257.5 \text{ sq. ft.} \\ \text{Index} &= \frac{5142.5}{6400} = .80 \end{aligned}$$

Changed Layout

$$\begin{aligned} q &= 6400 \text{ sq. ft.} \\ r &= 1687.5 \text{ sq. ft.} \\ \text{Index} &= \frac{4712.5}{6400} = .75 \end{aligned}$$

Interestingly enough, the layout change decreased the value of this index. The improvement eliminated waste production space by more compact

$$\left[ \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right]$$

1. Initial values of  $x$  and  $y$  are 1.0 and 1.0 respectively.  
 2. While  $x$  is not equal to  $y$ , do the following:  
 3.  $x = \frac{x + y}{2}$   
 4.  $y = \frac{x + y}{2}$   
 5.  $x = \frac{x + y}{2}$   
 6.  $y = \frac{x + y}{2}$   
 7.  $x = \frac{x + y}{2}$   
 8.  $y = \frac{x + y}{2}$   
 9.  $x = \frac{x + y}{2}$   
 10.  $y = \frac{x + y}{2}$

Initial values:  $x = 1.0, y = 1.0$   
 After 1st iteration:  $x = 1.0, y = 1.0$   
 After 2nd iteration:  $x = 1.0, y = 1.0$   
 After 3rd iteration:  $x = 1.0, y = 1.0$   
 After 4th iteration:  $x = 1.0, y = 1.0$   
 After 5th iteration:  $x = 1.0, y = 1.0$   
 After 6th iteration:  $x = 1.0, y = 1.0$   
 After 7th iteration:  $x = 1.0, y = 1.0$   
 After 8th iteration:  $x = 1.0, y = 1.0$   
 After 9th iteration:  $x = 1.0, y = 1.0$   
 After 10th iteration:  $x = 1.0, y = 1.0$

In the interest of brevity, only the first few iterations are shown. The values of  $x$  and  $y$  are always 1.0. This is because the initial values of  $x$  and  $y$  are 1.0, and the formula for calculating the next values of  $x$  and  $y$  is  $\frac{x + y}{2}$ . Since  $x$  and  $y$  are always 1.0, the result of the formula is always 1.0.

It is to be noted that the new values of  $x$  and  $y$  are always 1.0. This is because the initial values of  $x$  and  $y$  are 1.0, and the formula for calculating the next values of  $x$  and  $y$  is  $\frac{x + y}{2}$ . Since  $x$  and  $y$  are always 1.0, the result of the formula is always 1.0. This is a simple case of a fixed-point iteration, where the values of the variables do not change from one iteration to the next.

2. Initial values of  $x$  and  $y$  are 1.0 and 1.0 respectively.  
 3. While  $x$  is not equal to  $y$ , do the following:  
 4.  $x = \frac{x + y}{2}$   
 5.  $y = \frac{x + y}{2}$   
 6.  $x = \frac{x + y}{2}$   
 7.  $y = \frac{x + y}{2}$   
 8.  $x = \frac{x + y}{2}$   
 9.  $y = \frac{x + y}{2}$   
 10.  $x = \frac{x + y}{2}$   
 11.  $y = \frac{x + y}{2}$   
 12.  $x = \frac{x + y}{2}$   
 13.  $y = \frac{x + y}{2}$   
 14.  $x = \frac{x + y}{2}$   
 15.  $y = \frac{x + y}{2}$

Initial values:  $x = 1.0, y = 1.0$   
 After 1st iteration:  $x = 1.0, y = 1.0$   
 After 2nd iteration:  $x = 1.0, y = 1.0$   
 After 3rd iteration:  $x = 1.0, y = 1.0$   
 After 4th iteration:  $x = 1.0, y = 1.0$   
 After 5th iteration:  $x = 1.0, y = 1.0$   
 After 6th iteration:  $x = 1.0, y = 1.0$   
 After 7th iteration:  $x = 1.0, y = 1.0$   
 After 8th iteration:  $x = 1.0, y = 1.0$   
 After 9th iteration:  $x = 1.0, y = 1.0$   
 After 10th iteration:  $x = 1.0, y = 1.0$   
 After 11th iteration:  $x = 1.0, y = 1.0$   
 After 12th iteration:  $x = 1.0, y = 1.0$   
 After 13th iteration:  $x = 1.0, y = 1.0$   
 After 14th iteration:  $x = 1.0, y = 1.0$   
 After 15th iteration:  $x = 1.0, y = 1.0$

Interestingly enough, the values of  $x$  and  $y$  are always 1.0. This is because the initial values of  $x$  and  $y$  are 1.0, and the formula for calculating the next values of  $x$  and  $y$  is  $\frac{x + y}{2}$ . Since  $x$  and  $y$  are always 1.0, the result of the formula is always 1.0.



arrangements which showed up as an increase in aisle area. Actually this represents area available for production machinery which is exactly what we desire the index to tell us.

$$9. \text{ Time Index} = \frac{s}{t}$$

where  $s$  = The sum of the standard times for all operations on a part

and  $t$  = The total standard times for the part, raw stores to finished stores including handling time and time in banks

Initial Layout		Changed Layout	
Valve 308	$s = .10207 \text{ hr.}$ $t = 6.87815 \text{ hr.}$	$s = .10207 \text{ hr.}$ $t = 3.49011 \text{ hr.}$	
Index	$= \frac{.10207}{6.87815} = .0148$	Index	$= \frac{.10207}{3.49011} = .0292$
Valve 280	$s = .12123 \text{ hr.}$ $t = 8.16498 \text{ hr.}$	$s = .12123 \text{ hr.}$ $t = 4.14310 \text{ hr.}$	
Index	$= \frac{.02123}{8.16498} = .0149$	Index	$= \frac{.12123}{4.14310} = .0293$

As previously, the valve bodies were used as the basis of the above computations. Standard times for all operations on the valve body through machining, assembly and packaging were used.

It is noted that the layout change in both cases nearly doubled the index value. Even with the change, however, an extremely low index value exists indicating that the bank and handling standard times are all out of proportion to the operation standard times. This makes for a very high in process inventory which should be reduced.

$$10. \text{ Index of Human Comfort} = \frac{u + v + w}{3}$$

where  $u$  = A tabled area factor value



1. The first step in the process of identifying a problem is to define the problem. This involves identifying the symptoms of the problem and determining the scope of the problem. Once the problem has been defined, the next step is to identify the causes of the problem. This involves identifying the factors that are contributing to the problem and determining the underlying causes. Once the causes have been identified, the next step is to develop a plan of action. This involves identifying the steps that need to be taken to solve the problem and determining the resources that will be needed to implement the plan. Finally, the last step in the process is to implement the plan and monitor the results. This involves putting the plan into action and tracking the progress of the solution. Once the problem has been solved, the final step is to evaluate the results and determine if the solution was effective. This involves comparing the results of the solution to the original problem and determining if the problem has been resolved.

The total standing alone for the left, was shown to  
be about 100,000,000, which was also the

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As previously, the valve holder was used as the basis of the design.

It is noted that the typical example in each case nearly doubled the index value. Even with the caveat, however, as to why the index value exists indicating that the best and best-selling standard lines are all on the promotion to the special standard lines. This shows for a very high in process inventory which should be reduced.

10. Product of two numbers is  $3 \frac{1}{2}$  and  $4 \frac{1}{2}$  is  $15 \frac{1}{2}$ .

TABLE 1. *Continued*

$v =$  A tabled temperature factor value

and  $w =$  A tabled lighting factor value

All of the workers at the plant under study had more than sufficient working room in both layouts.

The temperature in winter is kept at or near 70° F and in summer it depends, of course, on the local weather conditions. Since the plant is exceptionally well ventilated it should not become appreciably warmer than the outside. Arbitrarily an average of 70° F is assigned.

Footcandle light meter readings were taken at 23 different locations throughout the plant morning and afternoon on cloudy days. No worker receives less light than would score a factor of 1.0 and the overall average of all the readings was 38.3 foot candles. The classification of the type work done at the plant is that listed for C in Table 3.

The above index in consequence of the foregoing is computed as follows:

From Tables 1, 2, and 3

$$u = 1$$

$$v = 1$$

$$w = 1$$

$$\text{Index} = \frac{1 + 1 + 1}{3} = 1.0$$

$$11. \text{ Inventory Index} = \frac{x}{y}$$

where  $x =$  The rate of production

and  $y =$  Time index

Since the plant surveyed is still operating sporadically, no rates of production can yet be established and consequently no inventory index can be computed. From the very low values of the Time Index it is seen that the Inventory Index would take on a very high value if computed.

7.2.1. Generalized Index

7.2.2. Indexing Group

All of the members of the group must have the same

weighting factor in the index.

The relationship between the index and the group is

defined, of course, in the index itself. Thus the index is

essentially a weighted average of the values of the

the index,  $I$ , is given by  $I = \frac{\sum w_i x_i}{\sum w_i}$ .

Problems arise when the index is not a simple average

throughout the group, and attention must be given to the

fact that the index is not a simple average of the

the results of the group. The relationship of the index

to the index is given by  $I = \frac{\sum w_i x_i}{\sum w_i}$ .

The index in the group is given by  $I = \frac{\sum w_i x_i}{\sum w_i}$ .

For index  $I$ ,  $I$ , and  $I$

$$I = I$$

$$I = I$$

$$I = I$$

$$I = \frac{I + I + I}{3} = 1.0$$

1.1. Inventory Index

where  $x$  = the value of the index

and  $y$  = the index

Since the index is a weighted average, the index

can be calculated as a weighted average of the index

computed. From the values of the index it is seen that the

inventory index is a very high value if computed.



## CRITIQUE

1. The Index of Indirect Materials Handling. This index appears to be sound, easily computed, and usable in any plant employing conveyors and/or sequential operation layouts. The latter consideration would probably confine the usefulness of this index to continuous manufacturing plants or to intermittent plants which tool up to manufacture continuously on large orders.

2. The Index of Direct Materials Handling. The same criticism as above applies to this index since the only way to obtain a very high index value is to align the production machinery sequentially in a direct line from raw stores to finished stores.

3. The Index of Gravity Utilization. This index appears to be sound, easily computed, and a valuable measure in any plant whether intermittent or continuous. It should be particularly useful in evaluating the layout of a multi-story concern.

4. The Prime Index of Automatic Machinery Loading. This index is believed to be a reasonable measure of the efficiency with which automatic machinery is arranged for operation by less than one person per machine. Accordingly it belongs in the field of plant layout evaluation criteria wherever automatic machinery is employed.

5. The Secondary Index of Automatic Machinery Loading. Essentially the same criticism as for the Prime Index holds true for this index. It can be used effectively to determine machine-man loading efficiency in odd cases such as the operation of 4 machines by 3 men. Since it is usable only for such odd cases, which are rare, it is believed to be of secondary value in plant layout evaluation.



1. The Index of General Economic Activity

General activity is measured by means of the index of general economic activity. The index is calculated on the basis of the movements of the index of economic activity and the index of general economic activity. The index of general economic activity is calculated on the basis of the movements of the index of economic activity and the index of general economic activity.

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6. The Index of Flexibility. The flexibility index appears easily usable in any plant, continuous or intermittent, where machines are moved into assembly lines for a specific product and which are rearranged to accommodate changes in product design. Accordingly it appears to be a sound index of layout evaluation for such plants.

7. The Index of Floor Area Loading Density. Since this index effectively measures efficiency of floor use it is held to be a criterion of layout. Fault may well be taken with the arbitrary assignment of machine profile area in a horizontal plane bordered by a one foot clear space as one measure in determination of the index. It can be argued that some large machines require extra area for loading and/or for repairs. The factors in the formula for the index were assigned because a start must be made at some place. A truer index would result from the "necessary" machine floor area divided by that portion of the total plant floor area available for machinery. This index serves intermittent, continuous or job shop layouts alike.

8. The Index of Aisle Wastage. Aisles serve two purposes - the movement of men and the movement of materials. In a theoretically perfect mass production layout where each work piece automatically proceeds from machine to machine, no aisles would be necessary, provided that reasonable access to work stations existed for personnel. In such a case this index takes on its maximum value. Note, however, that one condition is complete automatic materials handling. Such conditions would give Index 1, the Index of Indirect Materials Handling, a value of unity. Accordingly high correlation may exist between these two indices. The Index of Aisle Wastage does appear to be sound, simple to calculate, and of value as a layout criterion, especially in continuous and intermittent manufacture.

#### 6. The Index of Quantity. The Quantity Index is a ratio which

measures the change in the volume of goods and services produced in a country over a period of time. It is calculated by dividing the value of the current year's production by the value of the base year's production and multiplying the result by 100. The base year is usually the year in which the index is set equal to 100.

#### 7. The Index of Price and Income. The Price Index is a ratio which

measures the change in the price of a basket of goods and services over a period of time.

It is calculated by dividing the current year's price of the basket by the base year's price of the basket and multiplying the result by 100.

The Income Index is a ratio which measures the change in the income of a country over a period of time.

It is calculated by dividing the current year's income by the base year's income and multiplying the result by 100.

The Index of Price and Income is a ratio which measures the change in the price and income of a country over a period of time.

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The Index of Price and Income is a ratio which measures the change in the price and income of a country over a period of time.

It is calculated by dividing the current year's price and income by the base year's price and income and multiplying the result by 100.



9. The Time Index. This index seems of use only in continuous or specially tooled up intermittent plants. It is a strong indication of the time efficiency of travel of a part through the production process. As such it not only becomes a measure of plant layout but also of production control. The Time Index is believed to be a particularly powerful tool for evaluation of layouts.

10. The Index of Human Comfort. This index is believed to be of doubtful value in spite of the importance to the worker of the three components - heat, light and work area. With no light to work in, yet with adequate space and proper temperature, an individual score could be .67. Trouble arises also in taking averages of many values because it is the individual case that needs to be corrected when an unsatisfactory condition does exist. Although the components are individually of great importance, there appears to be no justification for combining them into one index or even of using them as individual indices. Accordingly this index, the Index of Human Comfort, is set aside.

11. The Inventory Index. This index takes on equal importance with the time index and is, of course, based on the time index. It tells immediately the number of production units planned for the production line. As such it quickly detects over banking and poor materials handling. Obviously this index is usable only in continuous manufacture, but can be used in an intermittent plant set up for continuous work on one or more products.



9. The Index. This index serves as a guide to the contents of the report, and is placed at the beginning of the report. It is a summary of the contents of the report, and is a very important part of the report. It is a summary of the contents of the report, and is a very important part of the report. It is a summary of the contents of the report, and is a very important part of the report.

10. The Index of Names. This index is placed at the end of the report, and is a summary of the names of the persons mentioned in the report. It is a summary of the names of the persons mentioned in the report, and is a very important part of the report. It is a summary of the names of the persons mentioned in the report, and is a very important part of the report. It is a summary of the names of the persons mentioned in the report, and is a very important part of the report.

11. The Summary. This index is placed at the end of the report, and is a summary of the contents of the report. It is a summary of the contents of the report, and is a very important part of the report. It is a summary of the contents of the report, and is a very important part of the report. It is a summary of the contents of the report, and is a very important part of the report.

## CONCLUSIONS AND RECOMMENDATIONS

Eleven indices of effective physical plant utilization have been proposed. One has been set aside as being of doubtful value. Of the remaining ten, all seem suitable and are recommended for evaluation of a continuous manufacturing layout with one considered to be of secondary importance. Three indices appear suitable and are recommended for evaluation of jobbing layouts. The intermittent plant may be evaluated by either three or ten indices depending upon whether it tools for continuous manufacture on some products. The employment of the indices as criteria of layout is recommended for:

### Continuous Manufacture

1. Index of Indirect Materials Handling
2. Index of Direct Materials Handling
3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading
5. Secondary Index of Automatic Machinery Loading
6. Index of Flexibility
7. Index of Floor Area Loading Density
8. Index of Aisle Wastage
9. Time Index
11. Inventory Index

### Jobbing

3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading
7. Index of Floor Area Loading Density

The indices, although presently usable, are significant only in comparing one layout of a plant with another of the same plant. There are no developed standards against which numerical values of the separate indices may be compared. Neither is there established any relative importance of the indices. It would seem, therefore, that a wide field of further study exists, namely -- that of relative order of importance of the indices, and that of the importance of specific index values. Also, since improvements in in-



dustry must pay for themselves in dollars and cents, an appropriate area of investigation would be the correlation of the criteria indices against costs.



In the following paragraphs we shall see that the results of the experiments are in good agreement with the theoretical predictions.

The first experiment was carried out with a sample of the material under investigation. The results of this experiment are shown in Figure 1. It can be seen from this figure that the results of the experiment are in good agreement with the theoretical predictions.



Fig. 1

The second experiment was carried out with a sample of the material under investigation. The results of this experiment are shown in Figure 2. It can be seen from this figure that the results of the experiment are in good agreement with the theoretical predictions.

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